PHYSICAL AND CHEMICAL EFFECTS OF PELLETING FEED ON BROILER GROWTH AND BEHAVIORAL PARAMETERS

by

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INTRODUCTION

Numerous reports have indicated that pelleting diets for broilers results in increased weight gain and improved feed efficiency. However, the exact mechanism involved, either physical or chemical or a combination of both, has been debated for several decades. Several theories have been suggested including: increased density that stimulated greater feed consumption, a reduction in time and therefore energy expended in feed prehension, increased nutrient utilization through mechanically-induced structural change, and several less quantifiable mechanisms such as a reduction in dusting and spillage loss and elimination of pathological bacteria and "anti-growth" factors.

Research conducted for this thesis was designed to evaluate those theories directly involved with physical or chemical influences of pelleting using an apparatus that continuously monitors feeding activity and overall consumption. The data were then condensed into behavioral parameters of meal size, meal frequency, meal length, and interval between meals over a predetermined time period. Both pelleted and unpelleted versions of the diet were further tested for possible biochemical variation in available starch, lysine, and metabolizable energy. Finally, a feeding trial was conducted to determine if increases in weight gain and feed efficiency could be affected by the degree of heat treatment during the pelleting process.

REVIEW OF LITERATURE

Chemical effects of pelleting

Extensive research indicates that the compaction of meal feedstuffs into granules through the pelleting process results in improved body weight gain, as well as increased feed efficiency of growing broilers. Improved performance due to pelleting was first noted by Heywang and Morgan (1944) who surmised that the increased performance was dependent to some extent upon relative feed consumption. This opinion was upheld by Hamm and Stephenson (1959), who found that equivalent amounts of mash and pelleted versions of the same diet resulted in similar gains. Conversely, Lanson and Smyth (1954) noted superior weights and feed conversion of broilers fed pellets vs mash with only minimal variation in feed consumption. They attributed improved performance to increased density of the pellets. McNaughton and Reece (1982) did not observe any differences in feed consumption between chickens fed mash and pellets containing three levels of metabolizable energy. Although birds on each treatment experienced weight gain, the advantage from pelleting was more pronounced with the lower energy diets.

Improved growth performance attained by pelleting broiler diets has been shown to be further accentuated with increased dietary fiber (Bearse *et al.*, 1952). This observation was further substantiated by Lindblad *et al.*

(1955) and Arscott et al. (1957), who substituted increasing levels of barley for corn in grower diets. Because barley contains a higher fiber level than corn, raising the barley content at the expense of corn increased the relative response in body weight gain as well as in feed efficiency realized with pelleting. It was proposed that the energy availability of barley was improved by pelleting. Auckland and Fulton (1972) obtained similar results by feeding diets that contained increasing levels of metabolizable energy while maintaining similar calorie/protein ratios. Chicks fed crumbles grew faster than corresponding groups fed mash diets, although the differences in growth were greater with the lower nutrient levels. Chicks that received crumbles consumed slightly more feed, resulting in insignificant increases in feed efficiency. Both Pepper et al. (1960) and Pesti et al. (1983) reported that the addition of animal fat to pelleted broiler diets markedly reduced the beneficial effects of pelleting. They postulated that pelleting was responsible for improved energy utilization because birds fed calorie-marginal diets experienced the largest differential in growth while raising the dietary energy level diminished the response.

Sell and Thompson (1965) determined that increasing fat levels in grower diets increased carcass energy, nitrogen, and weight gains as well as feed efficiency for chicks fed both mash and pellet diets with gain being superior for pelleted diets at each energy level. They illustrated the increase in available energy through a calculation in which carcass energy gain was divided by metabolizable energy intake to obtain what they termed "efficiency of energy utilization." Increases in the above parameter were accomplished without a corresponding increase in apparent metabolizable energy. Hussar and Robblee (1962) noted similar increases in growth, efficiency, and nitrogen retention without significant increases in classical metabolizable energy. They attributed their results to increased feed efficiency due to an increase in productive energy content of the pelleted diets. McIntosh et al. (1961) and Sibbald (1977) demonstrated that pelleting had no effect on apparent or true metabolizable energy, respectively.

Reddy et al. (1962) reported that pelleting did not affect apparent metabolizable energy, but significantly increased productive energy. They theorized that the calorigenic effect of pelleted feed was a result of a reduction in energy expenditure during prehension of feed. Jensen et al. (1962) substantiated this theory by observing the eating habits of chicks fed mash versus those fed pellets. Chicks fed mash spent 14.3% time eating while those fed pellets spent only 4.7%. Reddy et al. (1962)

attempted to eliminate the possibility of improved performance as a result of altered chemical composition by regrinding the pelleted portion of the diet to the particle size of the unpelleted mash. They were able to conclude that the increase in growth due to pelleting was not a result of increased nutrient availability as birds fed pelleted diets reduced to original size and density performed similarly to control birds fed mash.

Proudfoot and Sefton (1977) obtained similar results when mash broiler-finisher diets were fed with a collection of scalped fines acquired during the screening process from the same formulation. With particle size approximate to that of mash, no significant difference in performance between the two treatments was observed. Since feeding the pelleted form of the same diet following the removal of fines resulted in increased rate of gain, they were in agreement that density was responsible.

The previous research of Allred _et_ _al_. (1957) is in direct contradiction with the theory that performance enhancement of chicks fed pelleted diets was entirely due to increased dietary density. Allred and his co-workers pelleted and reground the individual components of a broiler diet and fed them separately with the remaining mash portions of a balanced diet. They were able to get a growth response with only the corn portion of the diet. The pelleted, reground diet in its entirety was found to have just under half of the growth-promoting ability of the diet fed as whole pellets. They concluded that physical density was responsible for most, but not all, of the response obtained by pelleting. They postulated that the remainder of the increased growth rate and feed efficiency was due to increased nutrient utilization from corn or the existence of a heat-labile growth inhibitor that is naturally present in the grain. In a second experiment, Allred (1957) subjected corn to various heat and moisture treatments including soaking, steaming, and autoclaving. After incorporating these treatments into a balanced diet, no further growth response was found. This led them to the conclusion that the mechanical alteration of the corn due to the friction generated by pelleting was responsible for the growth-promoting response. Hinds and Scott (1958) were able to confirm this response with corn through similar procedures.

Skoch *et al*. (1983) demonstrated that pelleting alters carbohydrate components of corn. By subjecting both pelleted and unpelleted samples of a corn-based diet to enzymatic hydrolysis, an improvement in the susceptibility of starch to beta amylase was detected. Feeding trials with growing swine indicated that a similar *in vivo* increase in starch digestibility does not occur, as no difference was noted in apparent metabolizable energy. The subjects, however, experienced both increased weight gain and feed efficiency. Further testing revealed that starch degradation was increased by dry-pelleting over that achieved by steam-pelleting. The lubricating effect of added moisture reduced the degree of friction encountered by material extruded in the process.

Liang *et al*. (1969) subjected sorghum grain to increasing increments of pressure. He found a direct correlation with starch availability by feeding the treated grain to previously fasted pre-ruminant calves while monitoring circulating glucose level.

Physical effects of pelleting

The conflicting evidence regarding chemical alteration as the means by which pelleting improves broiler growth parameters reduces the plausibility of the theory. With the exception of Brue and Latshaw (1981), however, who found that pelleting had no consistent effect on diet volume, it is agreed that pelleting diets tends to increase the physical density of the product. This evidence is an explanation of the fact that pelleting diets containing 20% cellulose did not reduce body weight when compared to broilers fed the mash version of the undiluted diet, while unpelleted diluted diets resulted in weight loss (Reddy *et al*., 1962). The increase in physical density as well as nutrient density with the addition of fat offers an explanation of the non-cumulative effect of fat and pelleting (Calet, 1965).

Observations of individual feeding habits by Jensen et al. (1962) allowed them to postulate that the decrease in time spent consuming pellets as compared to a similar quantity of mash could be accounted for by increased density. A similar reduction in time spent eating was recorded by Savory (1974) who noted that chicks offered pellets expended half as much energy as those chicks ingesting equal portions of mash. Leroy (1961) has postulated that the number and length of feeding periods are important factors in the utilization of energy by animals.

In order to interpret previous research and distinguish possible changes in behavioral patterns involving meal-taking, it is necessary to define the term. Duncan et al. (1970) defined a meal as a period of continuous eating uninterrupted by an interval of more than two minutes. Savory (1974) referred to meals as distinct bouts of feeding activity separated by other periods of activity. Jensen et al. (1962) equated meals with the number of trips to the feed trough while Barbato et al. (1980) referred to a meal as any period of feeding activity associated with the consumption of food, regardless of bout length.

Quantification of feeding behavior requires the continuous monitoring of the subjects' activity. This has been accomplished by several methods. Jensen et al. (1962) manually recorded feeding time with a stop watch and weighed feeders regularly. Wood-Gush (1959) used time lapse photography to measure feeding activity without distinguishing individual meals. Siegel et al. (1962) utilized photoelectric cells strategically located to record feeder approach and retreat without distinguishing individual feeding bouts. Squibb and Collier (1978) attached micro-infrared photocells to individual feeder containers that relayed activity to an event recorder. Feed and water consumption were logged daily. Van Hemel and Myer (1969) also used photoelectric cells and an event recorder to monitor food as well as water consumption. Duncan et al. (1970) and Duncan and Hughes (1972) monitored pecking responses on a paper trace located inside a Skinner box. Masic et al. (1974) placed feed pans on a strain gauge transducer which used voltage change to drive a potentiometric recorder. This enabled them to determine number of pecks, intervals between pecks and total feed consumption. Barbato et al. (1980) suspended feeders from photoelectric force transducers that relayed signals to a physiograph recorder. These researchers later mounted feeders on electronic load cells that relayed impulses to a data terminal (Barbato et al., 1982). Both systems recorded information that could be translated into meal size, meal length, meal frequency, and interval length.

Several factors have been demonstrated to influence the normal feeding patterns of chickens. These factors are largely environmental because animals eat small frequent meals when food is readily available. If the cost to procure food, however, increases while the animal is free to regulate both meal initiation and termination, frequency and duration differences occur in an attempt to alleviate the additional expense (Kaufman and Collier, 1983). Clifton (1979) experimentally increased the procurement cost of chicks and found the subjects increased consumption rate in order to compensate. Squibb and Collier (1979) noted the current selection of broilers for maximum growth requires a large caloric intake that alters normal feeding behavior. Masic _et_ _al_. (1974) found marked differentiations in feeding activity between growing broiler and layer males. Although consumption per gram of body weight was similar, layers tended to manipulate food while ingesting little.

Savory (1980) determined the proportion of time that Japanese quail spent feeding differed significantly when they were fed mash and pellet forms of the same diet. Although the interval between meals did not differ, meal length was almost halved for those birds fed pellets, resulting in slightly more meals per day. He conjectured that the difference in meal length reflected the fact that pelleting allowed the food to be consumed faster as meal size was similar. In a second experiment, Savory noted that subjects adapted to mash consumed larger quantities when offered pellets indicating a "novelty effect" and a preference for pellets. In other preference trials, Calet and Baratou (1964) experienced similar results and postulated that the extensively developed sense of touch enabled the birds to differentiate particle size with the beak.

Although it has been suggested that hunger and satiety mechanisms exist in quail (Savory, 1980), Duncan et al. (1970) argued that homeostasis of circulating nutrient levels is not involved with initiation of meals by fowl. They proposed that food intake is regulated by activating mechanisms in the digestive tract as short frequent meals facilitate fairly constant rates of digestion and absorption. Savory and Gentle (1976) concluded that the crop could not be involved as it is a diverticulum bypassed during diurnal feeding. The role of the gizzard is lessened as well, since fine-textured material is believed to pass relatively unimpeded. Richardson (1972) implicated the duodenum, as externally induced constriction immediately reduced food and water consumption.

If gastrointestinal mechanisms are involved in feeding behavior, the superior performance of pellets could possibly be due to increased rate of passage. Jensen _et al_. (1962), however, experimentally determined that there was no significant difference in passage rate of chickens fed mash or pellets by monitoring retention time. They did not note the hyperphagia of pellet-fed broilers claimed by Hamm and Stephenson (1959), McIntosh _et al_. (1961), or Auckland and Fulton (1972). Savory and Gentle (1976) reported similar rates of passage with quail fed diets containing increasing levels of fiber.

MATERIALS AND METHODS

Stocks and husbandry

The experimental subjects in the feeding trial were straight-run Barred Plymouth Rocks of university origin housed in 1.52 x 3.66 m floor pens at the rate of 40 birds per pen. The birds were reared from day 0 through 55 days of age in a controlled environment at normal brooding temperatures under a continuous lighting regime. Per-pen feed consumption and individual body weights were recorded at 14, 28, 42, and 55 days of age.

At 55 days of age, 16 cockerels were randomly selected and placed in individual cages under a similar environment with the exception that a photoperiod of 14 hr of light and 10 hr of darkness was maintained. The 8 birds that were later randomly selected for the metabolism trial were taken from within this population. At all times, a commercially balanced broiler-grower diet and water were provided *ad libitum*. Diet formulation and proximate analysis are listed in Table 1.

Feed preparation

Experimental subjects in all three experiments were fed various physical forms of the same diet weighed and mixed as one entity. Corn was ground on a 1/8 inch screen. The batch was bagged and the quantity to be pelleted was routed through a 150 horsepower pellet mill (Sprout-Waldron).

Pellets, crumbles, and reground material were all processed on a 2 x 11/64 inch stainless steel die, with preconditioned mash presented at 55, 70, or 85°C.

The temperature was continuously monitored by a microprocessor (Norvidan) that maintained a constant flow rate throughout the run. Crumbles were processed by a roller mill set to produce a particle size not greater than 0.25 cm. Reground pellets were prepared by churning in a Hobart laboratory mixer until 90% of the material passed through a 0.20 cm screen. Kjeldahl analysis for nitrogen revealed similar levels of crude protein for pellets and crumbles processed at 70°C and mash of the same formulation, immediately after processing. Moisture content remained within a range of 13.2 to 13.6%. Density of the following treatments was determined by weighing the quantity of feed that filled a 500 ml graduated cylinder. Results were as follows: 55°C pellets 406 g, 85°C pellets 402 g, crumbles 336 g, reground pellets 372 g, mash 388 g.

Experiment I

A total of 160 chicks were hatched in the university facilities, weighed, vaccinated against Marek's disease, and randomly placed in floor pens containing pine shavings as litter.

The birds were reared according to normal husbandry practices, with the exception that they were individually weighed at two week intervals. Birds in two pens received a crumbled broiler-grower diet pelleted at 55°C while those in the remaining two pens were fed the same crumbled diet processed at 85°C. At the conclusion of the experiment, feed efficiency and rate of gain were calculated and analysis of variance was used to determine the difference in treatment means. Duncan's multiple range test was performed to separate different means.

The following tests were performed to determine possible changes in nutrient availability. Apparent metabolizable energy trials for the unpelleted mash, 55, and 85°C treatments were conducted according to Han *et al*. (1976). This method requires total collection of feces over a 4-day period. Samples were taken daily and frozen until bomb calorimetry could be performed.

In order to determine the degree of starch gelatinization as a result of pelleting, an amylase digestion susceptibility test was performed on samples from the three treatments (Sullivan and Johnson, 1964).

Similar samples were also analyzed for biologically available lysine as extended heat treatment of the heat labile amino acid can result in the formation of an indigestible amino-sugar complex through the Maillard reaction. The procedure used was developed by Carpenter and Booth, (1973).

Experiment II

Twelve cockerels from the previously mentioned population were randomly selected at 8 weeks of age and placed in wire-floored individual cages. Birds were allowed to adapt to the facilities for a minimum of 28 days on a pelleted version of the aforementioned diet. At this time, 4 of the cockerels were transferred to a behavior-monitoring apparatus that consisted of individual 12 x 8 x 8 cm feeders mounted on load cells (Transducers, Inc.) with a rated capacity of 500 g. Impulses were translated by a microprocessor (Sterling Controls, Inc.) linked to an electronic data terminal calibrated to the nearest 0.1 ± 0.2 g (Huey *et al.*, 1982).

As feeding activity commenced, resulting in weight fluctuation, time to the nearest 5 sec interval, as well as feeder weight were recorded. As feeding persisted, each disruption was printed, allowing individual feeding bouts, or meals, to be determined. Meals were defined as a sequence of feeder disruptions including only those interruptions less than 2 min in duration (Duncan *et al.*, 1970) that resulted in the disappearance of not less than 0.5 g of feed.

Feed consumption data, in conjunction with feeding intervals, were further categorized as follows: meal size (g), feed consumed per lighted day (g), meal length(s), total time feeding per lighted day(s), rate of consumption (s/g), meal frequency, and interval length(s).

To determine the effect of particle size on feeding behavioral patterns, each bird's feeder was filled with a 100-g portion of pellets, crumbles, mash, or reground pellets and replenished daily over the 72-hour duration of the experiment. Means for the above variables were collected in 24-hour periods.

The above experiment was repeated with the remaining 8 birds to determine whether effects could be reproduced. Means for both experiments were pooled and analysis of variance used to test for statistical significance. Duncan's multiple range test was performed to separate different means.

Experiment III

As in Experiment II, 8 cockerels exposed to wire-floor, individual cages for over 60 days were randomly selected and transferred to the behavior-monitoring apparatus described previously.

To determine the effect of heat treatment on pelleted feeds, each feeder was assigned a 100-g portion of material pelleted at 55, 70, or 85°C, or a non-pelleted mash version of the same diet. These portions were replenished daily over the 72-hour duration of the experiment.

Feeding activity was again compiled into the variables listed for Experiment II. Means were collected in 24-hr periods and analysis of variance used to test for significance. Duncan's multiple range test was used to separate different means.

Table 1. Experimental diet

Ingredient	%
Corn meal	65.255
Soybean meal (48%)	24.000
Meat and bone meal	7.600
Animal fat	2.000
Limestone	0.400
Salt	0.300
Trace mineral mix*	0.050
Vitamin premix**	0.150
Choline chloride	0.030
DL-methionine	0.125
Amprol Plus	0.050
Bacitracin 40	0.025
Ethoxyquin	0.015
	100.000

	Calculated Analysis %	Assayed analysis
Crude protein	20.300	18.36
Crude fat	4.000	5.32
Crude fiber	4.000	2.71
Calcium	0.900	
Available phosphorous	0.440	
Lysine	1.100	
Methionine	0.465	
TSAA	0.801	
Metabolizable energy	3095 kcal/kg	2992 kcal/kg

*Supplies per kg of diet: 80 ppm iron, 20 ppm copper, 110 ppm zinc, 58 ppm manganese, 1800 ppm magnesium, and 0.18 ppm selenium.

**Supplies per kg of diet: 10,060 IU vitamin A, 2380 IU vitamin D_3, 42 IU vitamin E, 5 mg sodium menadione bisulfite, 3.6 mg thiamine HCl, 8.4 mg riboflavin, 57 mg niacin, 1560 mg choline, 27 µg cobalamine, and .45 mg biotin.

RESULTS AND DISCUSSION

Experiment I

Subjects fed pellets processed at 85°C experienced a significant increase ($P \leq .05$) in weight gain as compared to those fed the same formulation processed at 55°C (Table 2). Although there was no significant difference ($P \leq .05$) in total feed consumption, cockerels fed the diet pelleted at 85°C consumed an average of 36.8 g/bird/day while birds receiving the 55°C pellets averaged 30.2 g/bird/day (Table 3). The subjects offered feed processed at 55°C appeared to be more efficient, however, requiring only 2.18 g feed/g of body weight while the more rapid-gaining treatment birds consumed 2.50 g feed/g of body weight (Table 4). The lack of statistical significance given a range as great as this can be accounted for by variation encountered within the relatively small population number.

The above results are in contradiction of Pa'lsson and Verges (1952) who determined the most rapid gain in lambs was the most efficient due to a reduction in maintenance energy required to attain a specific weight. They attributed the increased rate of gain to optimal dietary plane of nutrition. Although diet composition between the two treatments of this trial was identical, the additional application of steam and moisture introduced several variables that could have altered nutrient bioavailability.

Hodge (1953) reported mild heat treatment of proteins was advantageous in that it resulted in preliminary denaturization that exposed peptide bonds to enzymatic hydrolysis. He noted, however, that extensive heating resulted in impairment of protein quality by the Maillard, or browning, reaction. The severe heat treatment of proteins has been shown to accelerate the production of Amadori Schiff bases from free amino acids within the polypeptide chain and the aldehyde group of reducing sugars such as glucose. The rearrangement yields a fructosyl-peptide complex that is no longer digestible by gastrointestinal enzymes. Carpenter and Booth (1973) observed that the epsilon amino group of lysine was the most susceptible to this degradation. Johnson et al. (1977) revealed that a similar reaction occurred with phenylalanine that resulted in significant ($P \leq .05$) depression of in vivo protein synthesis in chicks. Sgarbieri et al. (1973) reported that absorption of fructosyl-tryptophan was substantially less than that of the free amino acid in rats.

Although much has been reported concerning the reduced availability of essential amino acids following subjection to heat, very little information is available regarding temperatures necessary to produce these effects. Therefore, the reduction in availability incurred as a result of the 30°C differential can only be assumed. Lysine, the most heat labile amino acid, was experimentally determined to be 4.95% of crude protein for the 55°C treated pellets while 4.99% was unbound lysine for the 85° pelleted feed. As lysine is considered the most heat labile amino acid (Carpenter and Booth, 1973), and was not affected, it can be conjectured that the reduced feed efficiency of the birds consuming the 85°C pellets was not due to reduced amino acid availability.

The carbohydrate component of the diet, however, was altered considerably. Amylose and amylopectin, the primary constituents of cereal starch, are deposited in concentric layers encompassing the hilum of the grain kernel. The resulting crystalline structure is relatively insoluble and non-dispersible and therefore resistant to enzymatic attack (Leach and Skoch, 1961). The introduction of moisture in the presence of heat disrupts the inherent hydrogen bonding, causing the starch granule to swell and eventually rupture, facilitating amolytic attack (Sair, 1966). This process is called gelatinization. Liang et al. (1970) demonstrated that increased increments of pressure resulted in a positive, linear gelatinization response with corn processed by extrusion. Skoch et al. (1983) experienced a 46% increase in maltose equivalent between dry pelleted swine finisher diet and the unpelleted meal. The same formulation, however, yielded only a 20% increase with steam pelleting over meal. These results indicate steam pelleting is only 79% as effective at gelatinizing that particular diet compared to dry-pelleting. Performance data indicate no significant differences in rate of gain or feed conversion between hogs fed either diet, although subjects fed steamed pellets were slightly less efficient. Apparent digestibilities of dry and steamed pellets were similar indicating any possible nutritional response must occur post-absorptionally. The above results are in agreement with current findings. The diet processed at 85°C resulted in 53.7 mg/g maltose equivalent while the diet processed at 55°C yielded 56.3 mg/g. Both treatments produced greater extent of gelatinization than the unpelleted mash (46.0 mg/g).

The significant ($P \leq .05$) increase in weight gain can be hypothesized as a result of the trend towards increased feed consumption of the subjects offered the pellets processed at 85°C over subjects offered the 55°C diet. The increased rate of protein synthesis required for the superior growth rate of cockerels receiving the diet pelleted at 85°C demands additional protein as well as energy acquisition to fuel the obligatory metabolic activity. This need may be further accentuated by increased synthesis of pancreatic amylase generated to utilize less accessible starch polymers.

Since difference in physical density and uncorrected apparent metabolizable energy between pelleted treatments is negligible and precautionary measures were equivalently taken to minimize waste, the processing temperature differential could have affected any of the following factors that were not investigated. The elimination of pathological bacteria serves as a possible explanation for the increased growth rate of birds offered 85°C processed pellets. Dougherty (1976) isolated three strains of Salmonella from broiler feed samples prior to delivery. Further evaluation revealed S. derby and S. dry-pool serotype contamination from meat and bone meal, and S. seftenberg from fish meal. Coates _et_ _al_. (1981) identified Streptococcus faecium as being responsible for the growth depression experienced with nutrient malabsorption. They reported the involvement of the bacteria in the deconjugation of bile salts that are required for lipid absorption.

Although there is some possibility that the additional 30°C increase in temperature could thwart the multiplication of some bacteria, disinfectant capability is a function of length as well as extent of exposure. Pressure has also been shown to be a determinant of bactericidal effectiveness. Since pelleting is performed at atmospheric pressure and exposure to live steam is minimal, the extent of disinfection is limited. The antibacterial action of bacitracin, incorporated in the experimental diet, would further retard bacterial growth in the gastrointestinal tract.

Another positive factor derived from additional heat treatment involves the increased rate of chemical hydrolysis of bound organic phosphorous. Summers et al. (1966) reported chicks fed diets pelleted at 95°C gained significantly faster than chicks fed mash. No difference was noted, however, when both diets were supplemented with .28% inorganic phosphorous. These diets contained 25% wheat bran, and it is not known if phytin phosphorous is complexed to a lesser degree in wheat as opposed to corn, which was the major constituent of the broiler-grower diet used here. Lease (1966) autoclaved sesame meal and found that although the phytin phosphorous content had not changed, bone zinc from chicks fed diets containing 35% processed sesame increased over threefold compared with that of chicks fed unprocessed sesame meal. Although heat treatment is implicated in increasing the availability of these minerals, its effect in the current feeding trial can only be conjectured as zinc or available phosphorous analyses were not performed.

As the fat-soluble vitamins are particularly vulnerable to oxidation, they could have been responsible for the poorer feed conversion experienced with subjects fed the 85°C pellets as compared to those fed 55°C pellets. The increased application of steam required to precondition mash prior to pelleting could serve as a catalyst in the reaction, although a synthetic antioxidant was included in the diet.

Experiment II

Feed consumption rate was significantly increased in subjects fed pellets and crumbles as compared to birds fed mash and reground pellets (Table 5). The increase in rate of consumption significantly reduced the total feeding activity of birds fed the pellet or crumble versus those fed mash and regrind. This is in agreement with both Jensen et al. (1962) and Savory (1974) who noted that chicks fed mash took twice the time required to ingest a similar amount of pellets. Reddy et al. (1962) hypothesized that the reduced energy expenditure was responsible for the significantly ($P \leq .05$) greater productive energy obtained with a pelleted diet.

Savory (1980) reported that increased rate of consumption reduced meal length. Although subjects offered reground pellets experienced similar meal lengths as those fed whole pellets, birds fed the three processed diets ate significantly ($P \leq .05$) shorter meals than those offered mash. A plausible explanation for the smaller meal size of birds offered the reground pellet diet as compared to the remaining treatments, would be the existence of an unknown aversion for the material. Meal size, however, was not significantly different for any of the treatments. Savory and Gentle (1976) determined a reduction in physical density of quail diets increased the volume of feed ingested, while the weight, or meal size, was constant.

Jensen *et al*. (1962), Reddy *et al*. (1962), and Savory (1980) reported no significant difference in feed consumption among male broilers fed diets of varying particle size, as did Pesti *et al*. (1983) with broiler females. A similar conclusion can be derived from the present data. This indicates the increased consumption rate was balanced by reduced meal length. Both Jensen *et al*. (1962) and Savory (1980) postulated the energy saved by reduced prehension was shunted to the synthesis of protein and lipids required for elevated growth rate.

Particle size affected meal frequency inconsistently as cockerels offered mash made the fewest number of trips to the feeder while those fed reground pellets of similar dimension fed most frequently. Jensen *et al*. (1962), however, found no significant difference in meal frequency between chicks fed mash, pellets, or reground pellet diets. The observed increase in meal frequency of birds receiving reground pellets could be an attempt to offset the reduced meal size previously noted.

There was no significant difference in length of interval between meals among any of the four treatments. This is in agreement with Savory (1980) who reported particle size was not a determinant of interval length with quail fed pellet or mash versions of a similar diet.

Since all subjects were adjusted to a pelleted diet prior to experimentation, a possibility exists that the "novelty effect" observed by Calet and Baratou (1964) from changing mash-adjusted chicks to pellets could be reversed. The resulting aversion could possibly alter the responses obtained from mash diets. To avoid this situation, experimental design should include a Latin-square arrangement in which all subjects would be equally exposed to each treatment, regardless of pre-treatment.

As experimental stock was not representative of modern commercial strains, it would be of interest to repeat the above procedures with chicks having the genetic potential for rapid gain. Outcomes could then be compared to data obtained from lighter, hyperactive layer strains. Since the Barred Rock is a dual-purpose breed, the author suspects that present results lie somewhere between the above extremes. Masic et al. (1974) performed similar research with male broiler and layer strains and noted daily patterns of feeding activity differed markedly.

Experiment III

A significant ($P \leq .05$) difference in feed consumption rate was noted for birds offered the mash diet compared to that of birds fed pellets processed at 55, 70, or 85°C. The decreased consumption rate was responsible for a significant ($P \leq .05$) increase in feeding activity of the mash treatment over the diets pelleted at any of the three temperatures, as no difference was noted for meal size, meal length, meal frequency, or interval length (Table 6).

Several researchers, including Reddy et al. (1962), McIntosh et al. (1962), Hussar and Robblee (1962), Sibbald (1977), and Brue and Latshaw (1981) have determined the metabolizable energy of broiler diets is not affected by the pelleting process. These findings offer an explanation for the similarity in response between pelleted treatments. Since there were no obvious trends among the pelleted diets in any of the experimental variables, it must be concluded that heat treatment does not affect feeding behavior when particle size is held constant. With density of the pellet treatments being similar and greater than that of mash, it can be concluded that the physical effects of pelleting influence feeding behavior, and therefore growth parameters, to a much greater degree than chemical alteration.

GENERAL DISCUSSION

Although metabolizable energy for diets pelleted at 55 or 85°C was similar, the mash form of the diet was significantly ($P \leq .05$) less than that of processed diets (Table 7). While this finding counters previous research, the results could be explained by an increase in starch availability as a result of starch gelatinization that occurs during the pelleting process. Chemical alteration during pelleting was also reported by both Allred *et al*. (1957) and Sell and Thompson (1965) who observed significant increases in weight gain of broilers fed both whole and reground pellets as compared to those fed mash.

Conversely, Reddy *et al*. (1957) found no difference in weight gain of broilers fed mash or reground pelleted material of similar particle size, although identical formulations fed as whole pellets produced significantly ($P \leq .05$) improved weight gains. Pesti *et al*. (1983) reported similar performance improvement with crumbled diets that were consistently less dense than the original mash, as was true for this study.

Behavioral parameters, with the exception of meal length, were similar between subjects fed unpelleted mash and reground pellets of like particle size although metabolizable energy of the processed diet was greater than original mash. This leads to the conclusion that the benefit realized by pelleting diets is a result of the increased particle size that facilitates rapid prehension. Savory (1974) reached similar conclusions after determining that the apparent digestibility of a pelleted diet was superior to the unpelleted mash when offered to Brown Leghorn males.

Both Jensen et al. (1962) and Savory (1974) postulated the reduction in feeding activity as a result of pelleting improved the productive energy of the diet. Van Kampen (1976) substantiated this theory by monitoring the gaseous exchange rate of laying hens. Van Kampen calculated a 37% increase in heat production over resting levels during periods of feeding activity, attributing the majority to prehension and deglutition as heat production declined to only 113% of the original rate immediately following feeding.

CONCLUSIONS

The results of this study indicate that the increase in particle size due to pelleting is responsible for the increase in net energy obtained from pelleted diets. Both pellets and crumbles are considerably larger, more distinguishable, and therefore, more readily ingested than diets presented as mash. Pellets, being larger, reduced feeding activity to a greater extent than crumbles, although not significantly. The concurrent reduction in energy expended for feed prehension, increases the amount available to support growth.

The additional application of steam during the conditioning phase of pelleting, beyond that required to maintain pellet configuration, appears to be unnecessary. Additional steam diminished the generation of mechanical friction, which is responsible for the majority of gelatinization that occurs during the pelleting process. However, when pellet integrity is not maintained through adequate steam addition, the reduction in particle size associated with increased level of "fines," minimizes the performance advantage.

Table 2. Average weight gain of pen-reared Barred Plymouth Rock chickens through 8 weeks of age (Experiment I)

	Mash temperature following conditioning	
	55°C	85°C
Week 0-2	74.1 ± 5.76^a	81.6 ± 3.40^a
2-4	164.0 ± 2.39^a	175.0 ± 4.82^a
4-6	231.9 ± 0.11^a	246.1 ± 8.81^a
6-8	292.4 ± 3.44^a	307.4 ± 1.31^a
0-8	762.4 ± 6.91^a	810.0 ± 6.08^b

Means in the same row bearing different superscripts differ ($P \leq .05$).

Table 3. Feed consumption per bird of pen-reared Barred Plymouth Rock chickens through 8 weeks of age (Experiment I)

	Mash temperature following conditioning	
	55°C	85°C
Week 0-2	225.0 ± 3.44^a	236.0 ± 8.88^a
2-4	391.0 ± 44.36^a	406.7 ± 8.20^a
4-6	436.2 ± 54.35^a	569.9 ± 14.37^a
6-8	608.4 ± 95.68^a	813.5 ± 2.17^a
0-8	1660.5 ± 197.83^a	2025.9 ± 0.54^a

Means in the same row bearing different superscripts differ ($P \leq .05$).

Table 4. Feed conversion of pen-reared Barred Plymouth Rock chickens through 8 weeks of age (Experiment I)

	Mash temperature following conditioning	
	55°C	85°C
Week 0-2	3.05 ± 0.19^a	2.89 ± 0.01^a
2-4	2.39 ± 0.31^a	2.33 ± 0.11^a
4-6	1.88 ± 0.23^a	2.32 ± 0.14^a
6-8	2.08 ± 0.30^a	2.65 ± 0.01^a
0-8	2.18 ± 0.24^a	2.50 ± 0.02^a

Means in the same row bearing different superscripts differ ($P \leq .05$).

Table 5. Behavioral parameters of individually-quartered Barred Plymouth Rock cockerels (Experiment II)

Behavioral parameters	Particle Size			
	Mash	Pellets	Crumbles	Regrind
Meal length (sec/feeding)	507.1^a	235.1^{bc}	226.6^c	359.9^b
Meal size (g/feeding)	4.2^a	4.6^a	3.4^a	2.9^a
Consumption rate (sec/g)	122.7^a	69.5^b	78.5^b	135.2^a
Meal frequency (feedings/day)	20.3^a	24.0^a	26.5^a	35.0^a
Total feeding activity (sec)	10259.5^a	5417.6^b	5923.9^b	11937.6^a
Interval length (sec)	37.3^a	39.4^a	29.7^a	20.1^a
Total consumption (g)	85.6^a	100.8^a	89.1^a	93.0^a

Means in the same row bearing different superscripts differ ($P \leq .05$).

Table 6. Behavioral parameters of individually-quartered Barred Plymouth Rock cockerels (Experiment III)

Behavioral parameters	Mash	Mash temperature following conditioning 55°C	70°C	85°C
Meal length (sec/feeding)	279.9^a	142.3^a	131.3^a	197.3^a
Meal size (g/feeding)	1.7^a	1.7^a	2.6^a	2.4^a
Consumption rate (sec/g)	178.1^a	90.6^b	61.7^b	94.4^b
Meal frequency (feedings/day)	28.5^a	36.0^a	20.5^a	28.5^a
Total feeding activity (sec)	7998.6^c	5057.9^b	2599.6^a	5291.2^b
Interval length (sec)	25.8^a	21.6^a	41.8^a	29.9^a
Total consumption (g)	47.9^a	61.3^a	52.6^a	64.6^a

Means in the same row bearing different superscripts differ ($P \leq .05$).

Table 7. Apparent metabolizable energy* of the 3 dietary treatments with a replicate for each subject

	Treatment		
	55°C pellets	85°C Pellets	Mash
	3005.31	2968.14	2971.84
	3045.90	3130.08	2989.30
	2978.82	3039.86	2995.89
	3007.22	3081.52	3002.83
	3078.84	3037.75	2911.01
	3155.96	3095.45	2999.55
	3005.69	3000.60	3024.83
	3060.07	3070.63	3041.07
$\bar{x}$	3042.27^a	3053.00^a	2992.04^b

*Not corrected for nitrogen balance.

Means in the same row bearing different superscripts differ ($P \leq .05$).

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Appendix Table 1. Analysis of variance for the weight gain response of broilers fed 55°C pellets vs 85°C pellets (Experiment I)

Source	df	Sum of Squares	Mean Square	F value
Weight gain				
Total	3	2431.52		
Treatment	1	2262.23	2262.23	26.73*
Error	2	169.29	84.65	
Feed consumption				
Total	3	211812.48		
Treatment	1	133535.83	133535.83	3.41
Error	2	78276.65	39132.32	
Feed conversion				
Total	3	0.22		
Treatment	1	0.11	0.11	1.83
Error	2	0.11	0.06	

*Indicates statistical significance ($P \leq .05$).

Appendix Table 2. Analysis of variance for the behavioral response of broilers resulting from pelleting, crumbling, and regrinding vs a mash control diet (Experiment II)

Source	df	Sum of Squares	Mean Square	F value
Rate of consumption				
Total	11	15446.87		
Treatment	3	9406.31	3135.44	4.15*
Error	8	6040.56	755.07	
Feeding activity				
Total	11	121076570.85		
Treatment	3	92992567.17	30997522.39	8.83*
Error	8	28084003.69	3510500.46	
Meal length				
Total	11	192219.84		
Treatment	3	155846.61	51948.87	11.43
Error	8	36373.23	4546.65	
Meal size				
Total	11	14.11		
Treatment	3	5.58	1.86	1.75
Error	8	8.53	1.07	

*Indicates statistical significance ($P \leq .05$).

Appendix Table 2, cont'd.

Source	df	Sum of Squares	Mean Square	F value
Meal frequency				
Total	11	867.87		
Treatment	3	347.85	115.95	1.78*
Error	8	520.02	65.00	
Total consumption				
Total	11	3481.96		
Treatment	3	383.79	127.93	0.33
Error	8	3098.16	387.27	
Intervals				
Total	11	2220.14		
Treatment	3	689.38	229.79	1.20
Error	8	1530.76	191.34	

*Indicates statistical significance ($P \leq .05$).

Appendix Table 3. Analysis of variance for the behavioral response of broilers resulting from pelleting at three heat levels vs a mash control diet (Experiment III)

Source	df	Sum of Squares	Mean Square	F value
Rate of consumption				
Total	7	15907.81		
Treatment	3	15072.36	5024.12	24.05*
Error	4	835.45	208.86	
Feeding activity				
Total	7	32463075.39		
Treatment	3	29234104.75	9744701.58	12.07*
Error	4	3228970.64	807242.66	
Meal length				
Total	7	35449.59		
Treatment	3	27676.82	9225.61	4.75
Error	4	7772.77	1943.19	
Meal size				
Total	11	2.17		
Treatment	3	1.40	0.46	2.40
Error	8	0.78	0.19	

*Indicates statistical significance ($P \leq .05$).

Appendix Table 3, cont'd.

Source	df	Sum of Squares	Mean Square	F value
Meal frequency				
Total	7	398.87		
Treatment	3	240.37	80.12	2.02
Error	4	158.50	39.62	
Total consumption				
Total	7	548.31		
Treatment	3	352.00	117.33	2.39
Error	4	196.33	49.08	
Intervals				
Total	7	700.19		
Treatment	3	453.85	151.28	2.46
Error	4	246.33	61.58	

Appendix Table 4. Analysis of variance for the uncorrected metabolizable energy for mash, 55°C, and 85°C pellet treatments

Source	df	Sum of Squares	Mean Square	F value
Total	23	69356.29		
Treatment	5	35735.76	7147.15	3.83*
Error	18	33620.53	1867.81	

*Indicates statistical significance ($P \leq .05$).

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PHYSICAL AND CHEMICAL EFFECTS OF PELLETING FEED ON BROILER GROWTH AND BEHAVIORAL PARAMETERS

by

Stephen H. Combs

(ABSTRACT)

Barred Rock chickens were offered diets that had been pelleted at 55° or 85°C. In an 8-week feeding trial, the subjects receiving pellets processed at the higher temperature experienced significant ($P \leq .05$) weight gain over those receiving the diet processed at 55°C. Although feed consumption for this treatment increased as well, the difference was not significant ($P \leq .05$). Chemical investigation revealed that metabolizable energy and bioavailability of lysine of both heat treatments were similar. Starch availability as measured by *in vitro* enzyme susceptibility, however, was lowered by increased heat application.

In a second experiment, the feeding behavior of 12-16 week old cockerels offered diets of varying particle size, resulted in significant ($P \leq .05$) increases in feed consumption rate and therefore decreases in total feeding activity for birds offered pellets and crumbles as compared to mash and reground pellets. No differences were noted in

meal size, meal frequency, interval between meals, or total consumption.

In a parallel experiment, no differences were noted in the behavioral parameters of birds receiving diets pelleted at 55, 70, or 85°C of similar density and particle size. Mash controls, however, experienced significantly ($P \leq .05$) decreased consumption rate and concurrent increase in feeding activity.

The beneficial effects experienced with pelleting can therefore be attributed to the reduction in total feeding activity that allows an increased proportion of net energy to be utilized in support of growth.